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White Paper: OTN Capabilities in the NREN Environment

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Published in:
Connect

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

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Last updated:	08-07-2011
Activity and Task:	JRA1 T1
Target Audience:	NREN technical networking specialists
Document Code:	GN3-11-211
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The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7 2007–2013) under Grant Agreement No. 238875 (GÉANT).

1 Introduction

The Optical Transport Network (OTN) is evolving fast – a transformation, in fact, that renders the term "telecommunications architecture" somewhat obsolete. Plesiochronous and then Synchronous Digital Hierarchy (PDH/SDH) network infrastructures have become next-generation (NG) SDH architectures with OTN core transport, and now this is transforming further, into a next generation of end-to-end "transport" over OTN.

This next generation of OTN is the newest concept of converged core transport architecture, formed of a collection of standards initially written a decade ago but being completely renewed by the ITU-T, with input from the IEEE, the IETF, the OIF, the MEF and the TM Forum. The challenge is to address the delay sensitivities of data networking whilst utilising an architecture rich in Operation, Administration and Maintenance (OAM), all at ultra-high capacity.

In the light of these developments, hardware manufacturers are in the last phase of producing new equipment that can make use of the new features and add value to transport networks. The latest hardware combines Optical Channel Data Unit (ODU) switching with new features such as Tandem Connection Monitoring (TCM), additional ODUs and a standardised control plane.

Within the GÉANT project, GN3, Joint Research Activity 1 Task 1 (Future Network – Carrier Class Transport Network Technologies (JRA1 T1)) is evaluating these promising new features by defining test plans and specifications in close cooperation with manufacturers who are leading the development in this area. As a result of this work, a test report and evaluation of the technology will be published. The results of the Task's investigations into OTN to date are included in the GN3 Deliverable DJ1.1.1 – "Transport Network Technologies Study" [1].

This paper gives a brief description of OTN and its new features, and of how these could be used in an NREN environment. The paper also provides some hints about the direction in which the equipment providers are heading with regard to OTN switching technology.

In addition to the specific works referred to, the paper draws on the following sources: Josef Roese et al, "Optical Transport Network Evolving with 100 Gigabit Ethernet" [4] (Section 3.1); Martin Carroll et al, "The Operator's View of OTN Evolution" [5] (Sections 3.1 and 3.2); ITU-T Recommendation G.709/Y.1331, "Interfaces for the Optical Transport Network (OTN)" [6] (Section 3.1); and Ashwin Gumaste and Nalini Krishnaswamy, "Proliferation of the Optical Transport Network: A use case based study" [8] (Section 5).

2 OTN: Is It Really Something New?

OTN has existed since the 1990s. It was initially designed as the core transport mechanism for SDH, and has therefore been a carrier technology from the outset. However, OTN also aims to provide for the “carrier’s carrier” scenario by offering better OAM and improved control plane functionality.

To meet these requirements, the optical transport network has to evolve to become “Carrier Grade” and not “layer limited”. In its recent work plan, Study Group 15 of the ITU-T (ITU-T SG15) has noted that the OTN must deliver transport services focused on end-user requirements: it must be bandwidth capable, ensure low latency, provide or support Quality of Service (QoS), be low cost, low energy and either support or interact with flexible service delivery and billing mechanisms [2].

Initially drawn up with SDH core transport in mind, OTN is now adapting and reforming for IP and Ethernet core transport. This, therefore, is the “Packet Optical Evolution”. The Packet Optical Transport System, the Packet Optical Evolution, and Internet Protocol over Dense Wavelength-Division Multiplexing (IPoDWDM) are all essentially the same thing: Next-Generation Optical Transport Networking (NG-OTN). NG-OTN is OTN utilised as a transport infrastructure for IP packets and Ethernet frames, meaning that the next generation of OTN is designed to carry flow-oriented traffic, prone to bursts, not necessarily connection oriented, not necessarily synchronous. According to ITU-T, a Next-Generation Network (NGN) is:

> *A packet-based network able to provide telecommunication services and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent from underlying transport-related technologies. It enables unfettered access for users to networks and to competing service providers and/or services of their choice. It supports generalised mobility which will allow consistent and ubiquitous provision of services to users* [3].

This is a transformation of the first generation of OTN which, though suited to both synchronous and asynchronous data, was restricted to 2.5 Gb, 10 Gb and 40 Gb in a three-tier fixed design (ODU1, 2 and 3), with signal mapping for core carrier transport of SDH, Asynchronous Transfer Mode (ATM), Constant Bit Rate (CBR) and Generic Framing Procedure (GFP). Next-generation OTN adds at least two tiers of 1 Gb and 100 Gb (ODU0 and ODU4), and is designed for transport of traditional or “legacy” signals, as well as IP and Ethernet-based traffic. Notably, NG-OTN contains architectures particularly designed for 40 GbE and 100 GbE Ethernet transport, whilst also providing virtual circuits for low-order 1 Gb traffic.

The main characteristics of OTN, which make this technology an interesting player in the future of transport network architectures, are as follows:

- Combination of optical and digital layers providing network convergence: ITU-T G.872 defines the optical network architecture where the Optical Transmission Section (OTS), the Optical Multiplex Section (OMS) and the Optical Channel (OCh) are terminated. At the digital layer the Optical Channel Transport Unit (OTU), the Optical Channel Data Unit (ODU) and the Optical Channel Payload Data Unit (OPU) are defined.
- Flexible client signal mapping to meet market demands: OTN was originally designed for mapping SDH/SONET client signals, but was subsequently “extended” in order to support Ethernet in all its different variants.

- ODU multiplexing structure, which allows multiplexing of different signals into bigger transmission pipes, in turn allowing network optimisation and future growth.
- Forward Error Correction (FEC), which helps identification and correction of transmission errors, extending the transmission of traffic for longer distances and higher rates without the need for Reamplification, Reshaping and Retiming (3R) regeneration.
- Operation, Administration and Maintenance (OAM) similar to SONET/SDH and Tandem Connection Monitoring (TCM), allowing end-to-end service monitoring across multiple domains.
- High bandwidth: The ITU-T G.709 standard defined interfaces and rates going from OTU1 (2.666 Gb/s) to OTU3 (43.018 Gb/s) and, more recently, OTU4 (111.81 Gb/s).
- Survivability: The OTN standard includes protection mechanisms and automated restoration combined with control plane protocols.

As mentioned above, OTN is evolving, and ITU-T SG15 has been working on the standardisation of new features such as ODU0 and ODUFlex, new rates for high-speed client signals and delay measurement capabilities among others. Moreover, equipment manufacturers are developing new hardware that provides OTN switching capabilities. The intention behind this equipment is to provide convergence between the optical and digital layers and to address the requirements of carriers' networks. The next section describes the key recent developments and features.

3 Recent Developments in OTN

3.1 Mapping of High-Speed Client Signals

Initially, the G.709 standard was developed to carry legacy SONET/SDH traffic, but due to market demands and the evolution of transport networks it was decided that OTN had to be extended to support Ethernet. To solve this challenge, the G.709 multiplexing structure was extended with new formats, as shown in Figure 3.1. Specifically, the multiplexing hierarchy was extended to support the mapping into OTN of 1 GbE / 10 GbE / 40 GbE / 100 GbE.

Some of the Optical Transport Units had to be modified to support the mapping of certain interfaces, such as 10 GbE-LAN, for example. For this reason, the ITU-T issued a Supplement document (G.Sup43 [7]), which defined ODU2e/OTU2e and ODU3e/OTU3e (over clocked 44 Gb to carry 4 x 10 GbE-LAN). There are two solutions for ODU3e/OTU3e: the first, named ODU3e1, is based on Asynchronous Mapping Procedure (AMP); the second, named ODU3e2, is based on Generic Mapping Procedure (GMP). For 100 Gb OTN transport, the ITU-T has defined ODU4/OTU4 and has chosen a bit rate of 111.809974 Gb/s, in order to provide 80 tributary slots for up to 80 ODU0 and up to 10 ODU2e. Not only the hierarchy but also the mapping procedures were extended to include GMP, as this procedure had some advantages compared to existing ones due to its elasticity to bit-rate differences in the client signals. The evolution will not stop there, as the industry is already planning the extension of the structure by adding an OTU5. The question that still needs an answer is which signal should be mapped: 400 Gb/s or 1 Tb/s?

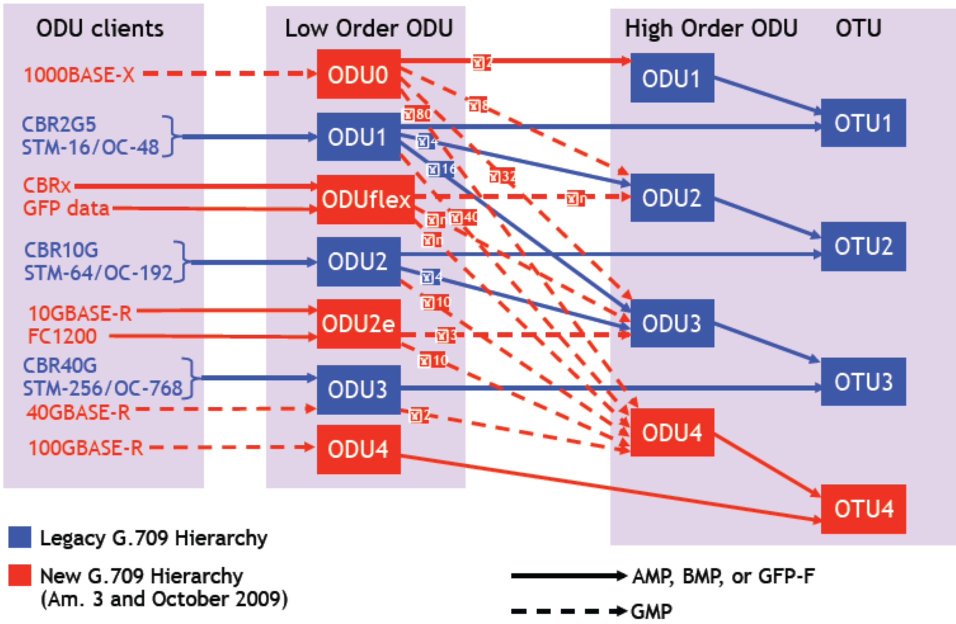

Figure 3.1: G.709 OTN multiplexing structure

3.2 ODU0 and ODUFlex

As explained above, the OTN client mapping capabilities were extended to support new requirements. ODU0 was added to support efficient transparent transport of GbE signals over OTN. It was required because if a GbE were to be mapped into an ODU1, half of the bandwidth would be wasted. However, an ODU0 container is half the size of an ODU1. This allows the mapping of two ODU0s into an ODU1 (as shown in Figure 3.2), which is then mapped into an OTU1. Notice that OTU0 does not exist.

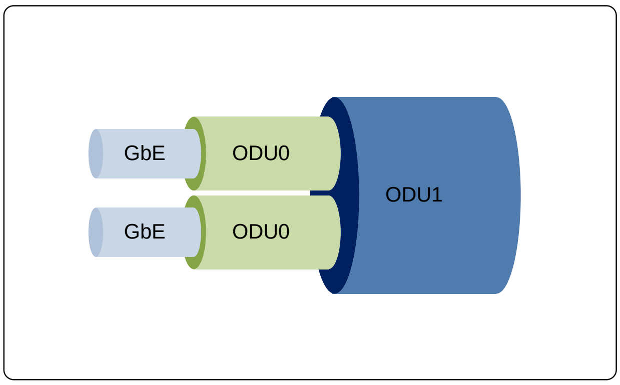

Figure 3.2: OTN ODU0

Additionally, ODUFlex was developed to accommodate signal rates of different speeds; it is sized to occupy the minimum number of time slots in a higher order ODUk. The client mapping is done so that the ODUFlex container has the exact size of its client, leaving the remaining space for other client signals as shown in Figure 3.3. ODUFlex supports Constant Bit Rate (CBR) clients and packet-based clients. CBR clients are mapped by using Bit-Synchronous Mapping Procedure (BMP) and packet-based client signals are accommodated by using Frame-mapped Generic Framing Procedure (GFP-F). ODUFlex is then mapped into a number of time slots in a High-Order ODU (HO-ODU) by using Generic Mapping Procedure (GMP).

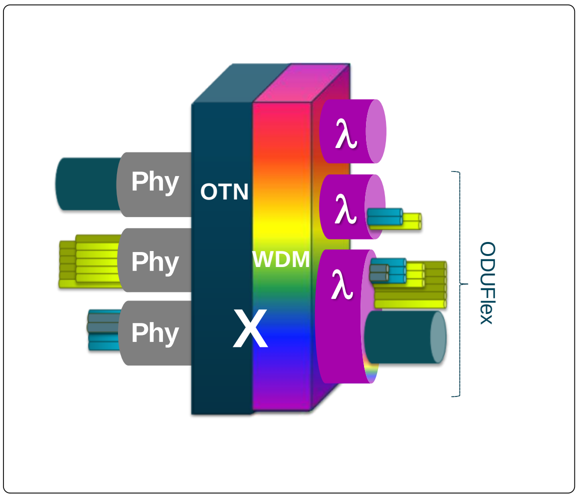

Figure 3.3: OTN ODUFlex

3.3 Automated Restoration

The OTN standard describes protection and restoration mechanisms similar to the well-known mechanisms in the SONET/SDH standard. However, due to the addition of a control plane protocol, OTN is now capable of automated restoration. This is achieved by means of the GMPLS as control plane. As shown in Figure 3.4, an OTN path can be rerouted via an alternative route in case of a network failure. The nodes use Open Shortest Path First with Traffic Engineering (OSPF-TE) protocol to build topology information about the network. This information is present on every node in the network and Resource Reservation Protocol with Traffic Engineering (RSVP-TE) is used to signal the paths along the network during the building or tearing down process of the path. The restoration can be done at both the optical and digital layer; however, the restoration at the optical layer would take longer, due to the inherent characteristics of lambda switching.

Automated restoration allows the reduction of pre-allocated bandwidth for protection and of manual intervention by a network operator to configure a backup path, thus reducing both CAPEX and OPEX in the network. On the other hand, network planners would have to design the network so that there is always an alternative route with sufficient bandwidth available in case of a link failure.

Automated restoration is especially interesting used in combination with the recently added capability for measuring delay in the OAM bytes. In very large networks with mesh topologies, it is necessary to be able to find the most suitable route across the network so that delay-sensitive applications are not affected by the selection of a long path.

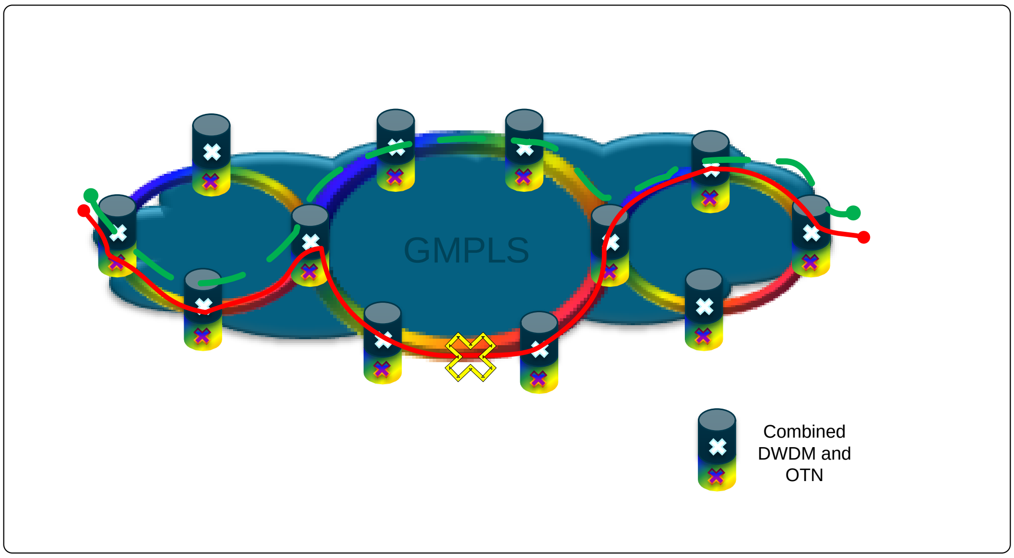

Figure 3.4: Automated restoration via GMPLS

3.4 Operation, Administration and Maintenance (OAM) Features

Research and education networks tend to operate in multi-domain/multi-vendor environments, thus facing the challenge of providing end-to-end monitoring and performance guarantees of the provided services.

Sustainability of these services relies on the use of cutting-edge networking technologies and on high-quality operational support. One of the advances OTN offers, compared to legacy systems, is the improved Operation, Administration and Maintenance (OAM) capability, which recognises former limitations by comprehensive reinforcement of the existing principles.

With the specification of the External Network to Network Interface (E-NNI) supplemented by the advances in Tandem Connection Monitoring (TCM), OTN offers a standardised interchange point, in which critical signal information is intact, thus enabling end-to-end multi-domain monitoring capabilities.

OTN OAM functionality adapts many of the capabilities developed for the SONET/SDH technology and expands them for the OTN electrical layers. Of the many advantages OTN OAM offers, the following are regarded as particularly relevant to the NREN community:

- Several protection schemes are available: OCh 1+1, OCh-SPRing, ODU-1+1 linear, ODU-SNC/I, ODU-SNC/N, ODU-SNC/S, and ODU-SPRing.
- A mesh restoration and recovery mechanism can also be used, based on ASTN (Automatically Switched Transport Network) standards.
- Enhanced maintenance capabilities (electrical and the optical layers).
- Full ODU path or section end-to-end monitoring capabilities (e.g. TCM advancements).
- Option to manage optical in-line amplifiers and overhead information of associated OCh, OMS, and OTS signals.

OTN supports six levels of independent Tandem Connection Monitoring (TCM) (Figure 3.5) allowing various configurations for TCM, such as nested and cascaded domain monitoring. This capability permits parallel monitoring for a path transmitted over multiple administrative domains/carriers and different segments of the path. In contrast, SDH/SONET only allows cascaded monitoring (one level).

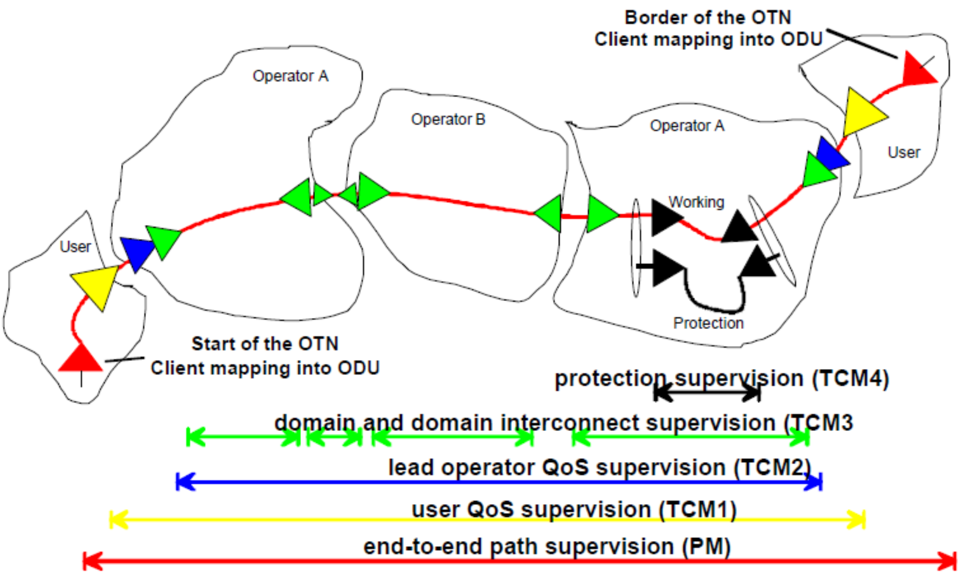

Figure 3.5: Tandem Connection Monitoring

3.5 Bandwidth on Demand (BoD)

Bandwidth on Demand (BoD) is “on demand” data transfer with deterministic performance to other end users with similar capabilities. The connection to the NREN through regional or campus networks can be done using a static assigned connection (typically VLANs). This means that the end user will need to have a permanent interface to the service provider, but hereafter the connections can be established on demand, i.e. dynamically.

The bandwidth-on-demand service can be very useful when researchers (end users) want to exchange data in a deterministic way (i.e. using guaranteed, specified bandwidth) with multiple researchers at other locations who have access to the service. This service is expected to be useful for high-performance computing centres, radio-astronomy, particle physics and bioinformatics.

OTN technology in combination with a standardised control plane provide a perfect environment for developing applications and tools to provide BoD services across multi-domain and multi-vendor networks. A standardised control plane and a well-defined E-NNI avoid the need for proprietary and temporary solutions that only work in some networks under very specific conditions. OTN multiplexing and switching capabilities provide the necessary granularity for delivery of packet-based dynamic services with very specific requirements for Quality of Service (QoS). OTN is definitely a transport technology to consider for deploying BoD services in the near future.

3.6 New OTN Hardware

Major network manufactures are developing new hardware that will hit the market in the coming months. The new hardware is intended to provide an answer to the growing demands for flexible, scalable, and easy-to-operate networks, while keeping both CAPEX and OPEX as low as possible. Carriers are demanding network convergence to reduce complexity, footprint and power consumption. At the same time, due to bandwidth increase, they are demanding support for higher rates of up to 400 Gb/s and 1 Tb/s in the future. These big transmission pipes will require switching and multiplexing capabilities in the network in order to accommodate different data rates and so allow network optimisation. In addition, carriers will have to support robust OAM capabilities and survivability schemes in order to comply with demanding Service Level Agreements (SLAs).

For the reasons mentioned above, vendors are going to launch hardware with OTN switching capabilities. Some of the solutions integrate Reconfigurable Optical Add-Drop Multiplexer (ROADM) functionality with OTN to achieve optical-digital convergence, providing full non-blocking Optical Transport Hierarchy (OTH) switching and multiplexing. The hardware provides Time Division Multiplexing (TDM) support for legacy services (SONET/SDH) and packet support with interfaces going from 1 GbE to 100 GbE. It is equipped with a universal switching matrix capable of switching up to 4 Tb. Moreover the equipment is GMPLS capable, to provide automated restoration among other possible applications.

Typical applications for OTN switches would be metro and core applications and router interconnect depending on the form factor.

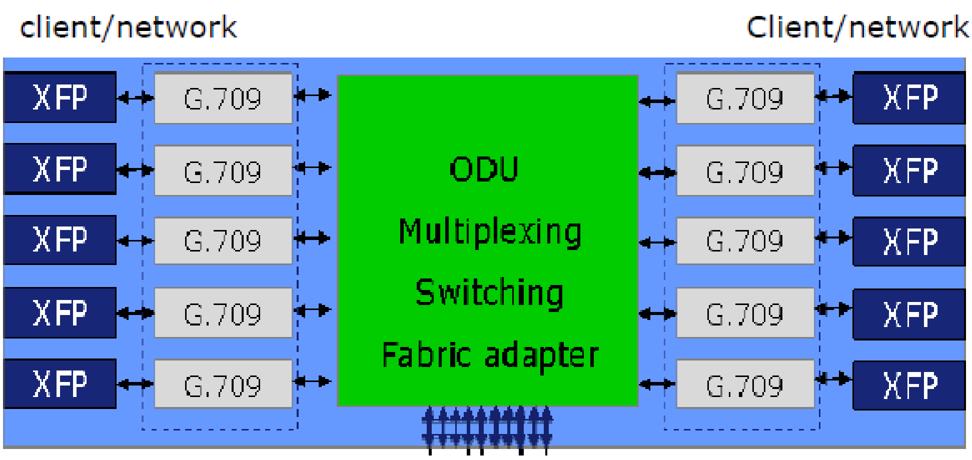

Figure 3.6: Universal switching fabric

4 NRENs' Motivation

Most NRENs are planning and designing their future networks, and OTN is one of the technologies they are considering. NRENs as well as commercial operators are asking such questions as: Why do we need OTN? Is OTN just a substitute for legacy services like SONET/SDH? What are the benefits? What prerequisites have to be in place for OTN to be a feasible option? The implementation of new networks always involves big investments, thus there have to be persuasive arguments behind such a decision.

So, what is the motivation for deploying OTN? As already explained, OTN was designed for transporting legacy client signals like SONET/SDH, but has recently been extended with new features to address the challenges of future transport networks. OTN is targeted at big transport networks needing flexibility, scalability and advanced OAM. The following OTN features add benefit to transport networks:

- Forward Error Correction (FEC): FEC provides detection and correction of transmission errors, allowing longer transmission distances without repeaters, and higher rates, resulting in CAPEX savings.
- Operation, Administration and Maintenance (OAM): ITU-T G.709 defines the use of the Optical-Electrical-Optical (OEO) conversion that is done at 3R regenerator points to provide OAM capabilities in the digital domain. OAM features in OTN allow monitoring capabilities similar to the ones in SONET/SDH. Moreover, Tandem Connection Monitoring (TCM) allows monitoring of end-to-end services across a multi-domain network, while keeping operational expenses to a reasonable level. TCM provides better monitoring capabilities, thus reducing troubleshooting time and endless communication between operation centres.
- Delay measurements: OTN is capable of selecting the most suitable path in case of restoration, taking into account the delay measurements. This option is very important for some of the delay-sensitive applications running in large networks.
- Standardised E-NNI: The NREN environment is a multi-domain environment where different organisations connect with each other using different technologies and different vendors. Standardised exchange points make the planning, provisioning and monitoring of services more efficient, by reducing cost and operational resources.
- Client mapping and multiplexing: With the introduction of ODU0 and ODUFlex, OTN provides a flexible mapping of client signals, and a multiplexing structure that provides network optimisation.
- Standardised control plane: GMPLS allows automated restoration in case of a network link failure, thus reducing troubleshooting time and manual intervention from the network operators. GMPLS also facilitates the development of applications for BoD services.

5 OTN Integration in Current Network Architectures

OTN technology and the forthcoming hardware will provide network convergence across layers. Integrated OTN switching capabilities in ROADM equipment will allow mapping, multiplexing, and switching of client signals. Finally, this traffic will be carried over lambda connections across the network. This concept is depicted in Figure 5.1. Client signals like Ethernet, SDH or ODUx can be mapped into ODUxs that are multiplexed into a higher order ODU that eventually can be switched at another point in the network. In the very near future all core links will be 100 GbE and higher, while the client signals will still go from 1 GbE. This puts some constraints on the design and planning of transport networks. There is a need to groom the client traffic in order to fill up the bigger pipes.

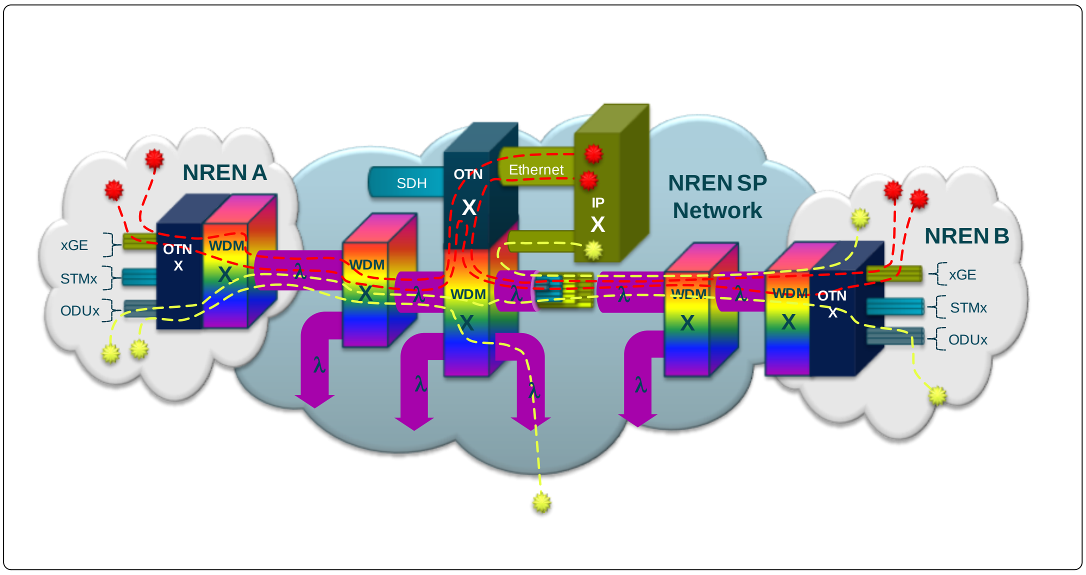

Figure 5.1: OTN network architecture

Figure 5.2, shows how an OTN switch can be used for exchanging traffic between different NRENs. The OTN switch is in charge of providing a defined and standardised way of interconnecting domains. Moreover, TCM will provide the possibility of end-to-end monitoring of services across domains.

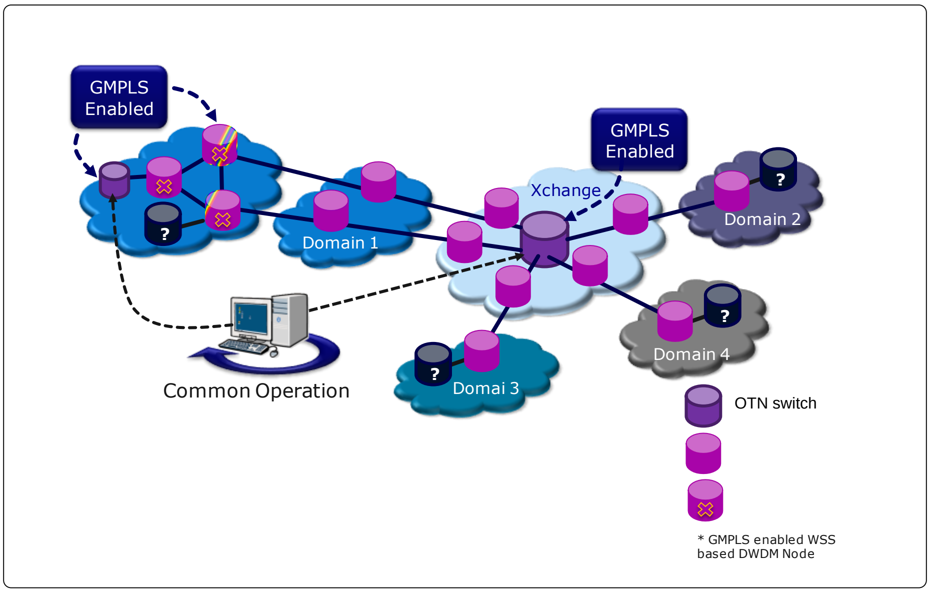

Figure 5.2: OTN exchange point

Another possible application of OTN in the NREN environment is IP offload, also known as router bypass, which has been promoted by transport equipment manufacturers. The main argument is that by using router bypass it is possible to reduce network cost and increase network scalability.

There are two possible options for interconnecting IP backbone routers. The first option is to use optical colour interfaces directly in the routers to connect to the DWDM network. This solution provides IP/DWDM convergence while maintaining the ability to monitor and manage the network. A second option is to use OTN interfaces in the router and use the OTN switching capabilities of the DWDM equipment. This option allows router bypass, meaning that the traffic will come to the router level only at the ingress and egress points (Figure 5.3).

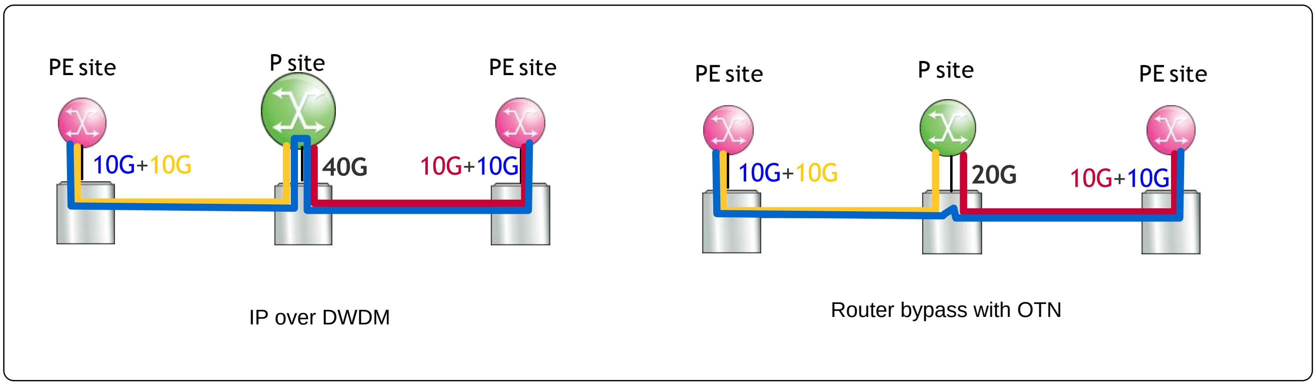

Figure 5.3: Router bypass with OTN

Router bypass is an option that should be considered in the NREN environment, but whether it is applicable or not will depend on future network architectures and their traffic flows, and will need to be investigated. It will probably be of benefit under specific conditions. It is up to the NRENs to find out where and how this application can be used in order to benefit from it.

6 JRA1 Task 1 OTN Testing Plans

As part of JRA1 Task 1 in the GN3 project, several NRENs are planning to test different OTN technology features. To date this has been very difficult to achieve, as most of the functionality described in this document is still not present in production equipment. However, the JRA1 Task 1 team has secured the cooperation of some interested vendors, and organised OTN testing at the vendor premises. The testing will be carried out according to test specifications defined by JRA1 T1 in close collaboration with the vendors. The goal is to discover possible weaknesses, establish proof of concept and mainly focus on the advantages of the technology itself. The following main interest areas have been selected for testing:

- OTN and ODU switching.
- Client signal mapping: ODU0 and ODUFlex.
- Tandem Connection Monitoring (TCM).
- Vendor interoperability.
- Survivability: protection and restoration.
- Automated provisioning in OTN.
- Management separation between optical and OTN elements.

The tests will cover these areas, but the scope could be extended as testing progresses. All test specifications and test results will be published as part of the second JRA1 T1 deliverable, which is due 31 March 2012.

7 Summary

OTN is currently under debate in many different forums. The standardisation developments introduced by ITU-T SG15 and the new hardware that will be commercially available in the coming months suggest that OTN is here to stay. This document has given a brief introduction to OTN and its features, and described the main advantages of OTN technology and how the NREN community can benefit from them. Finally, it has outlined the current plans of JRA1 Task 1 regarding the testing of OTN in close cooperation with vendors. The results of those tests, together with the findings of any further investigation and the latest status of standardisation and hardware developments, will be published at the end of Q1 2012. The report will provide GÉANT and NRENs with a reference document for use in the specification of their next-generation networks, helping them to determine whether OTN is an appropriate and feasible technology for their network.

Appendix A Vitae

Alberto Colmenero joined NORDUnet in September 2007 as an Optical Network Architect. Since then he has been working on the design and specification of Ethernet Network Services. His area of responsibility covers the Alcatel TSS network, where he is responsible for defining new services, customer solutions, network documentation and planning for network evolution. Alberto holds a BSc in Telecommunications Engineering and during his 10 years' experience in the telecommunications industry he has been involved with the design and implementation of IP, ATM, SDH, ADSL access networks and transport networks for UMTS.

Rasmus Lund is an Optical Network Architect at NORDUnet where his main responsibilities are in the future developments of NORDUnet's DWDM network. He is also involved in various GN3 projects, both in Service Activities and in Joint Research Activities (SA2 and JRA2). Rasmus has over 10 years' experience in the telecommunications field, primarily from the industry, but also from working at the Danish railway incumbent. Rasmus's main focus areas have been development and project management as well as gathering experience with testing and system administration. Rasmus holds a BSc in Telecommunications Engineering.

Anna Vasileva Manolova is a post-doctoral researcher in the Networks Technology and Service Platforms group within the Department of Photonics Engineering at the Technical University of Denmark. Since receiving her PhD from the same group in 2010, she has been working on diverse research topics related to control plane technologies, next-generation transport networks, quality of service and quality of transmission provisioning as well as survivability in optical networks.

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Glossary

3R	Reamplification, Reshaping and Retiming
AMP	Asynchronous Mapping Procedure
ASTN	Automatically Switched Transport Network
ATM	Asynchronous Transfer Mode
BMP	Bit-synchronous Mapping Procedure
BoD	Bandwidth on Demand
CAPEX	Capital Expenditure
CBR	Constant Bit Rate
DWDM	Dense Wavelength-Division Multiplexing
E-NNI	External Network to network Interface
FEC	Forward Error Correction
GE	Gigabit Ethernet
GFP	Generic Framing Procedure
GFP-F	Frame-Mapped Generic Framing Procedure
GMP	Generic Mapping Procedure
GMPLS	Generalised Multiprotocol Label Switching
HO-ODU	High Order ODU
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPoDWDM	Internet Protocol over Dense Wavelength-Division Multiplexing
ITU-T	International Telecommunication Union – Telecommunication Standardisation Sector
JRA1	GN3 Joint Research Activity 1: Future Network
JRA1 T1	JRA1 Task 1: Carrier Class Transport Network Technologies
LAN	Local Area Network
MEF	Metro Ethernet Forum
NG	Next Generation
NGN	Next-Generation Network
NG-OTN	Next-Generation OTN
NG-SDH	Next Generation Synchronous Digital Hierarchy
NREN	National Research and Education Network
OAM	Operation, Administration and Maintenance
OCh	Optical Channel
ODU	Optical Channel Data Unit
OIF	Optical Internetworking Forum
OMS	Optical Multiplex Section
OPEX	Operational Expenditure
OPU	Optical Channel Payload Unit
OSPF-TE	Open Shortest Path First with Traffic Engineering
OTH	Optical Transport Hierarchy
OTN	Optical Transport Network

OTS	Optical Transmission Section
OTU	Optical Channel Transport Unit
PDH	Plesiochronous Digital Hierarchy
QoS	Quality of Service
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RSVP-TE	Resource Reservation Protocol with Traffic Engineering
SDH	Synchronous Digital Hierarchy
SG15	ITU-T Study Group 15 – Optical transport networks and access network infrastructures
SLA	Service Level Agreement
SNC	SubNetwork Connection
SNCP	SubNetwork Connection Protection
SNCP/I	Inherently monitored SubNetwork Connection Protection
SNCP/N	Non-intrusively monitored SubNetwork Connection Protection
SNCP/S	SubNetwork Connection Protection with Sublayer monitoring
SONET	Synchronous Optical Networking
SPRing	Shared Protected Ring
TCM	Tandem Connection Monitoring
TDM	Time Division Multiplexing
TMF	TeleManagement Forum
VLAN	Virtual Local Area Network
XFP	10 Gigabit Small Form Factor Pluggable